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Interaction point simulations: Benchmarking progress

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LUXE weekly meeting

- Independent crosschecks essential for validation of interaction point (IP) simulations
- Comparing results already produced with IPstrong and my own particle-tracking code (https://github.com/tgblackburn/ptarmigan)
- Comparing with QED theory for plane waves and focused pulse (with thanks to Ben King)

IP simulations

Overview

- Emission rate calculated for a plane EM wave with a slowly varying amplitude and frequency (locally monochromatic approximation)
- Quantity that enters the rate is the quasi-momentum $q^\mu = \langle \pi^\mu \rangle$, which is a cycle-averaged quantity, and the local parameters $\langle a^2 \rangle$ and $\eta = k.q/m^2$.
- Equation of motion is the relativistic ponderomotive force $\dot{\boldsymbol{q}} = -\frac{m^2}{2q^0} \boldsymbol{\nabla} \langle a^2 \rangle$

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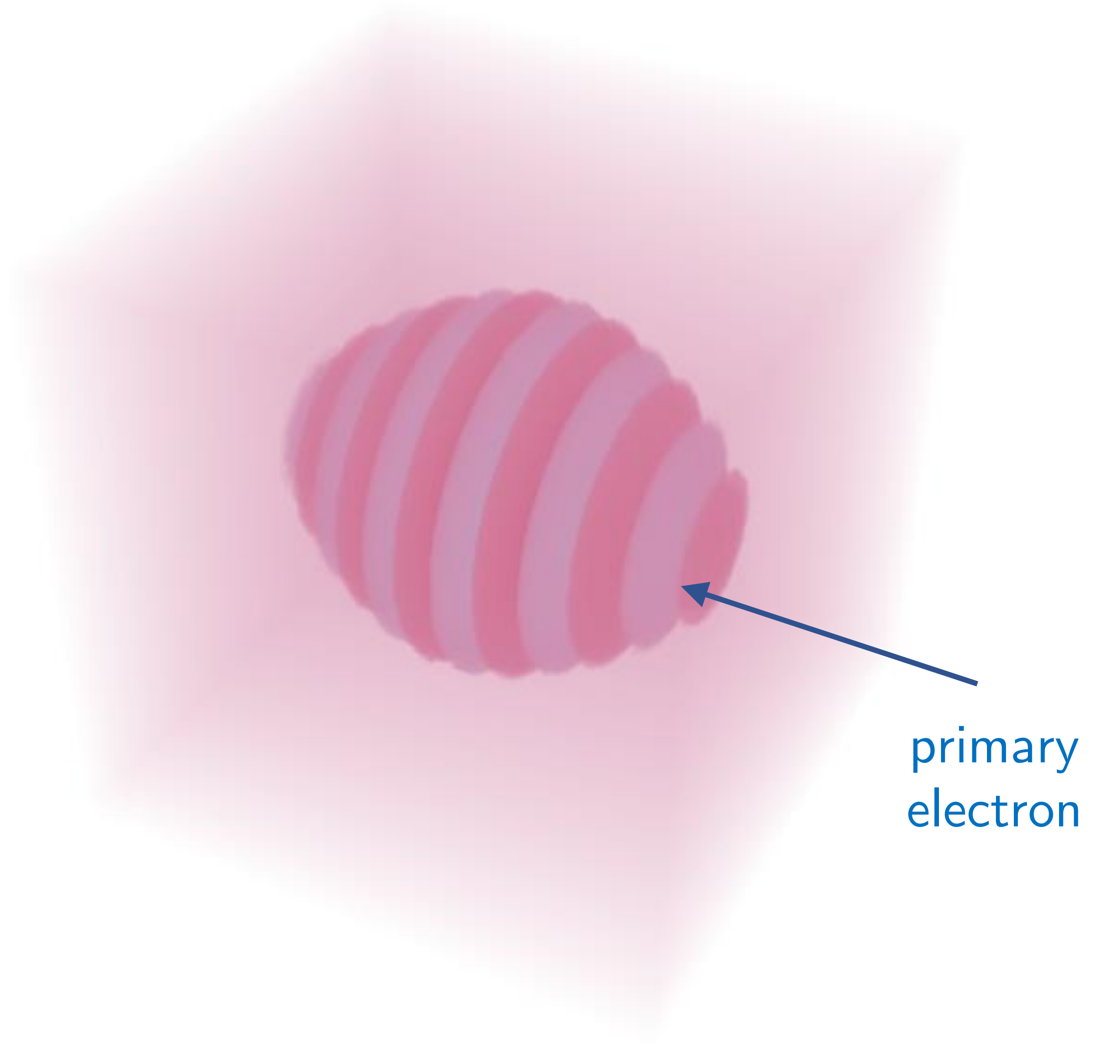

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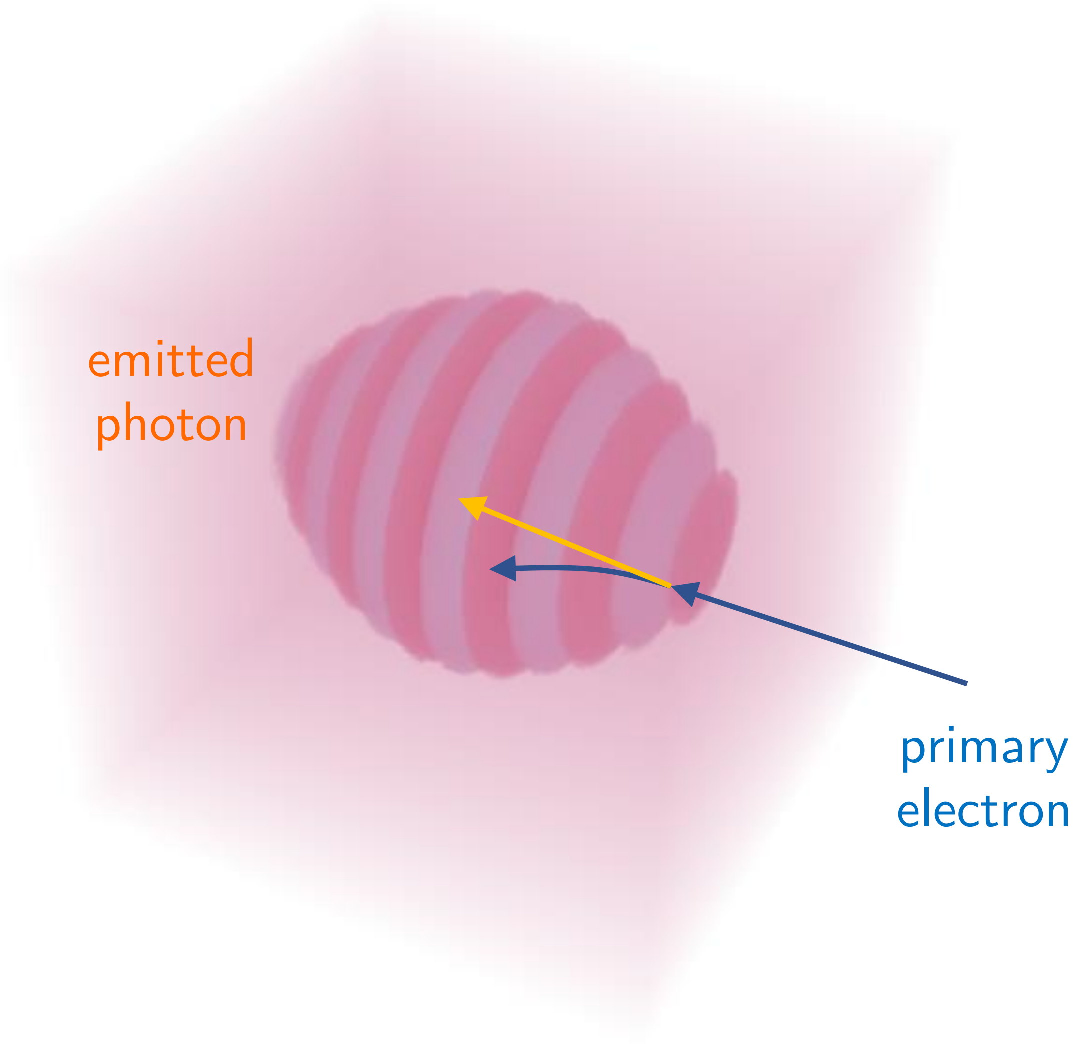

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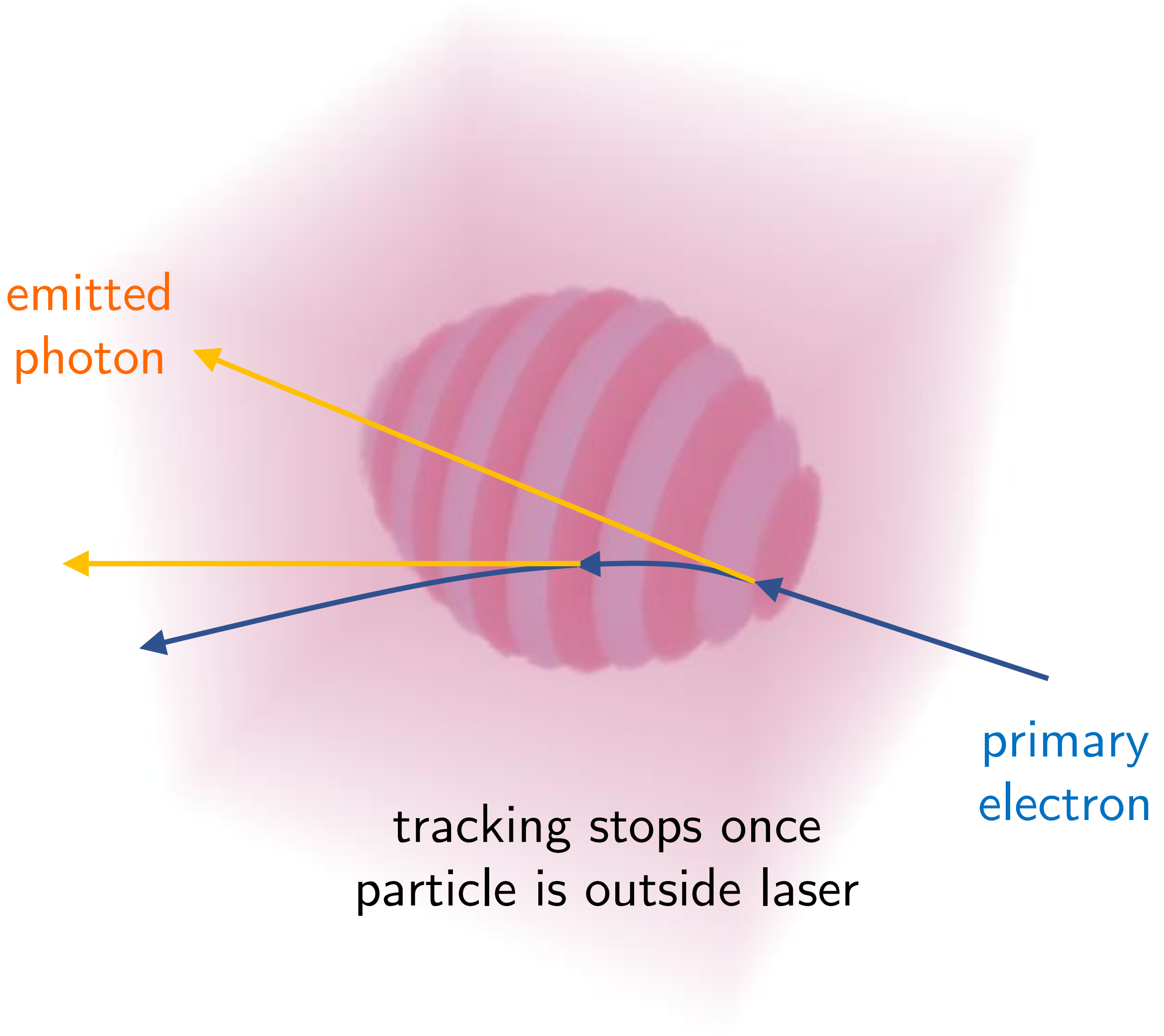

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Benchmarking

Overview

- Simulations are based on an approximation to the underlying theory (strong-field QED)
- Theoretical results available for **pulsed plane waves** and (under the high-energy approximation) **focused Gaussian beams**
- See, e.g., [Di Piazza PRA 95, 032121 (2017)], talk by Ben King

Laser polarisation: Gaussian background — UNIVERSITY OF PLYMOUTH — B. King 5/14

- "High energy" approximation (WKB in inverse lightfront momentum):

$$\mathsf{P} \approx \int d^2\mathbf{x}^{\perp} d\varphi \underbrace{\rho(\mathbf{x}^{\perp})}_{\text{probe density}} \frac{d\mathsf{P}^{\mathrm{pw}}\left[\xi\left(\varphi, \mathbf{x}^{\perp}\right)\right]}{d\varphi}$$

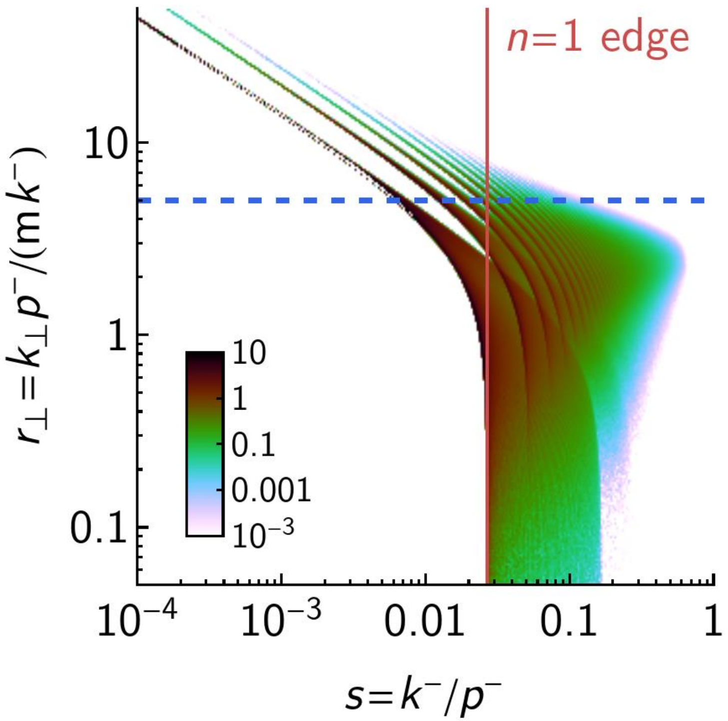
- Gaussian focussing

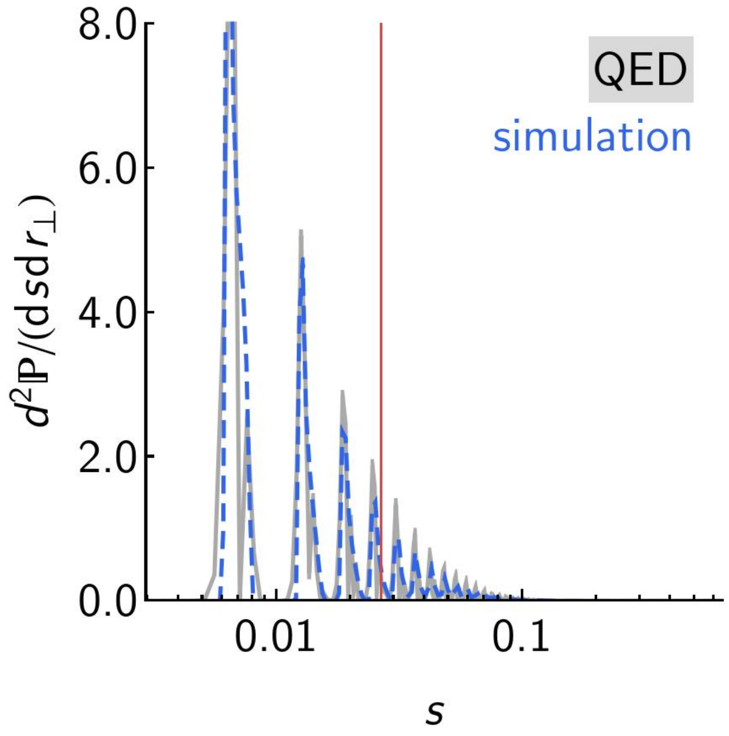
$$\xi\left(\varphi, \mathbf{x}^{\perp}\right) = \xi_0 \frac{w_0}{w(-\varphi/2)} \exp\left[-\left(\frac{\mathbf{x}^{\perp}}{w(-\varphi/2)}\right)^2\right] \underbrace{g\left[\left(\frac{\varphi}{\Phi}\right)^2\right]}_{\text{envelope}}$$

$$w(z) = w_0\sqrt{1+\left(\frac{z}{z_r}\right)^2}$$

- But no wavefront curving (would require extending LMA)

Pulsed plane wave, $a_0 = 2.5$





- Compare photon spectra in terms of lightfront and perpendicular momenta.
- Here $\eta = 0.1$ (electron energy is 8.4 GeV, laser wavelength is 800 nm).
- Pulse temporal envelope is $\cos^2$ in electric field, 16 wavelengths long.

Benchmarking

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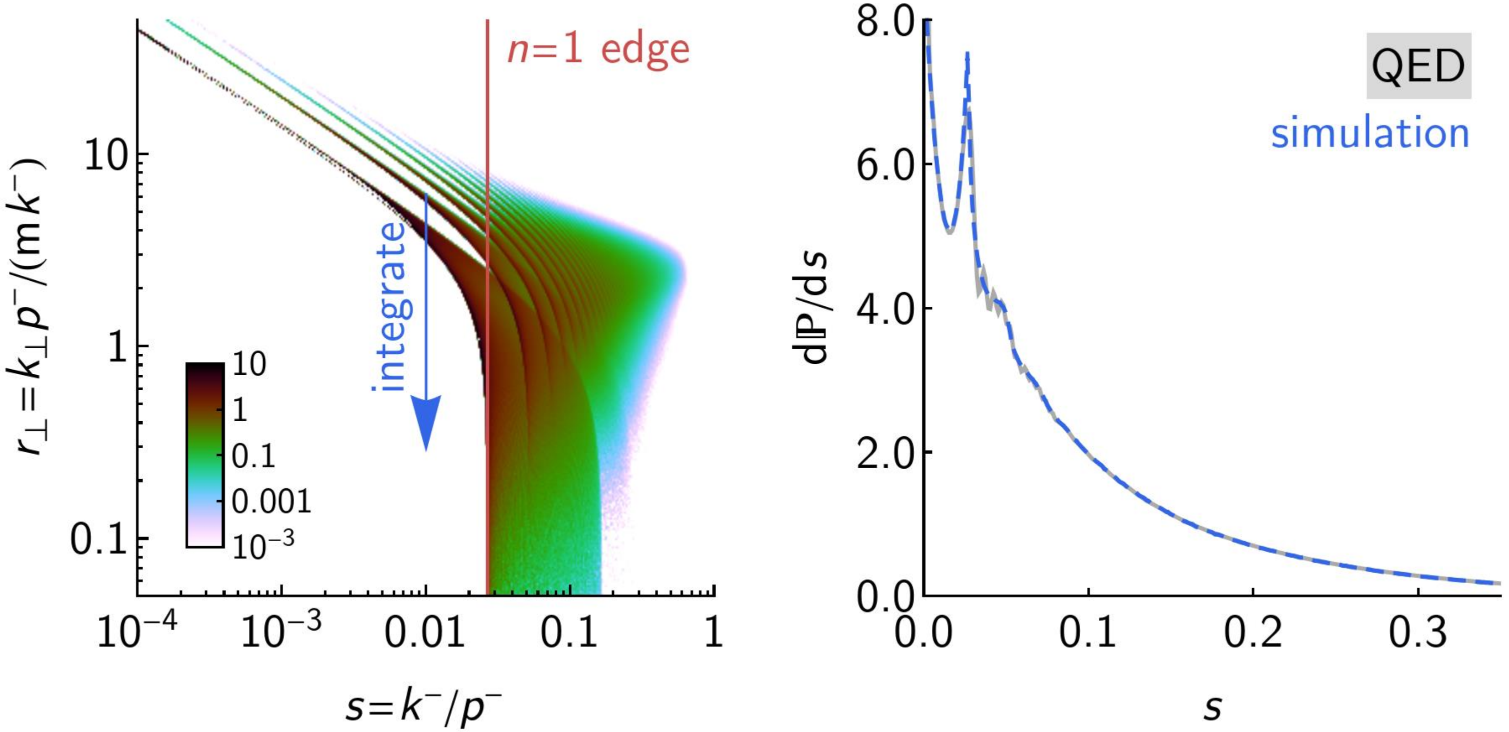

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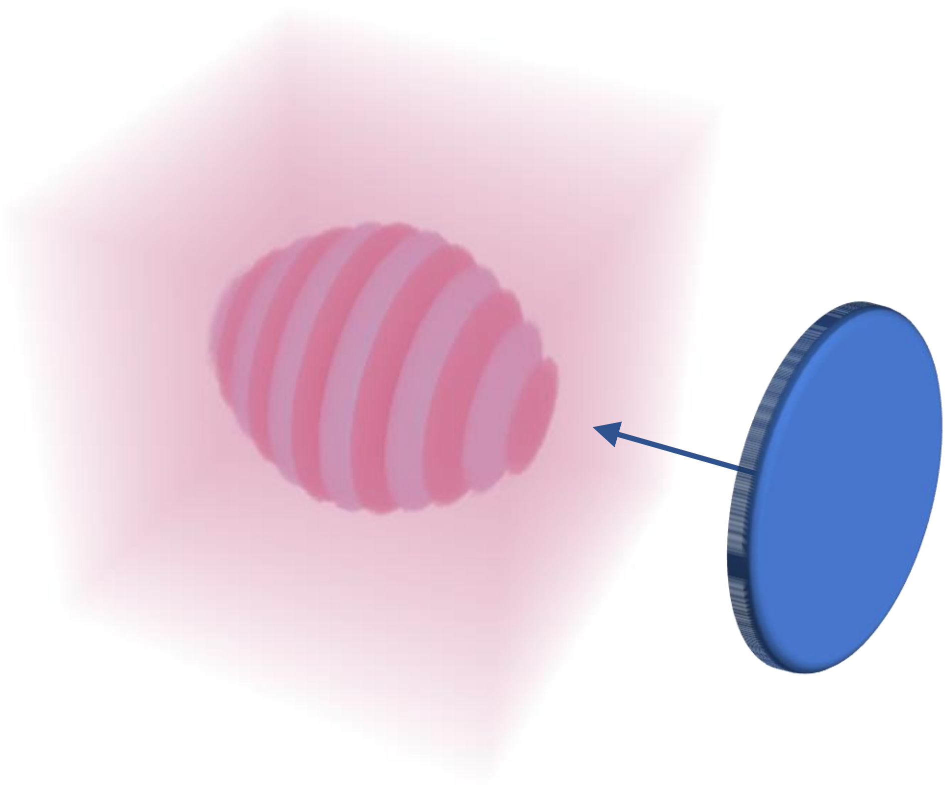
Focused pulse, $a_0 = 2.5$

- Recently extended comparison to include 3D effects (impact parameter averaging)
- Consider a thin disk of electrons, distributed uniformly around collision axis (radius twice the focal spot size)
- Here $\eta = 0.1$ (electron energy is 8.4 GeV, laser wavelength is 800 nm); pulse is $\cos^2$ in electric field, 16 wavelengths long; waist $w_0 = 4$ micron



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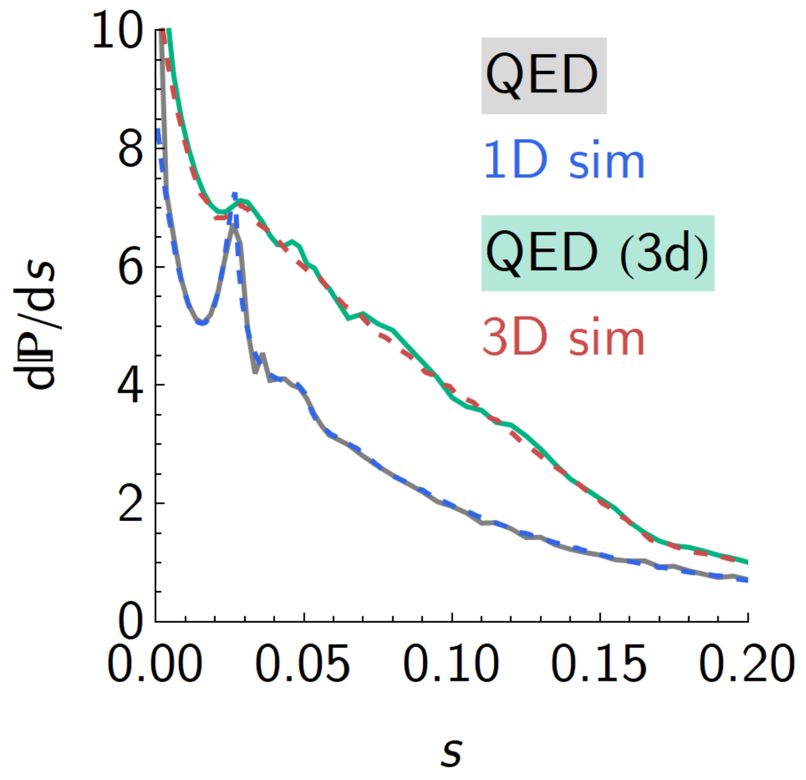

3D results scaled up by 10×

Cross-checks

Using latest IPstrong results

- Sourced from `/afs/desy.de/user/h/hartin/public/IPstrong_V1.1.00/superseded_data/JETI40/e_laser_provisional_10xi^3_HICS/` and `JETI40/e_laser/`

- Sum more harmonics and "fix normalization of NLC process"

- Three different focal spot sizes

- Need to reconstruct initial conditions

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- Duration is FWHM (electric-field!) – so 25 fs (IPstrong) is equivalent to 18 fs.

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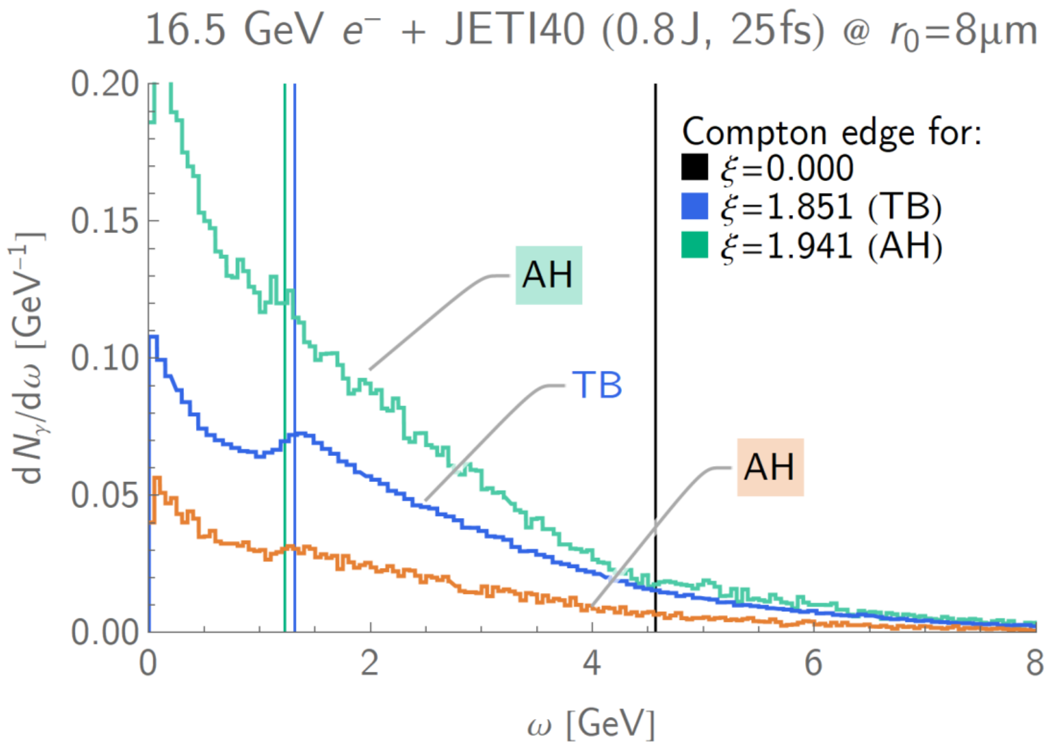
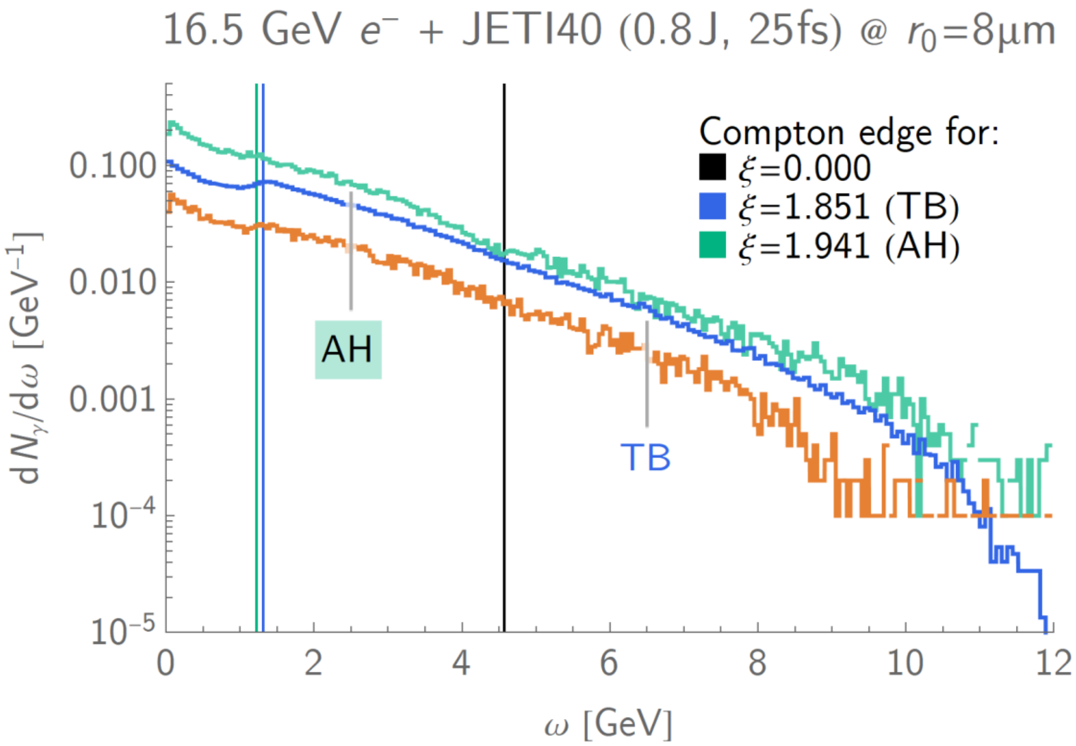
Cross-checks

$r_0 = 8$ microns

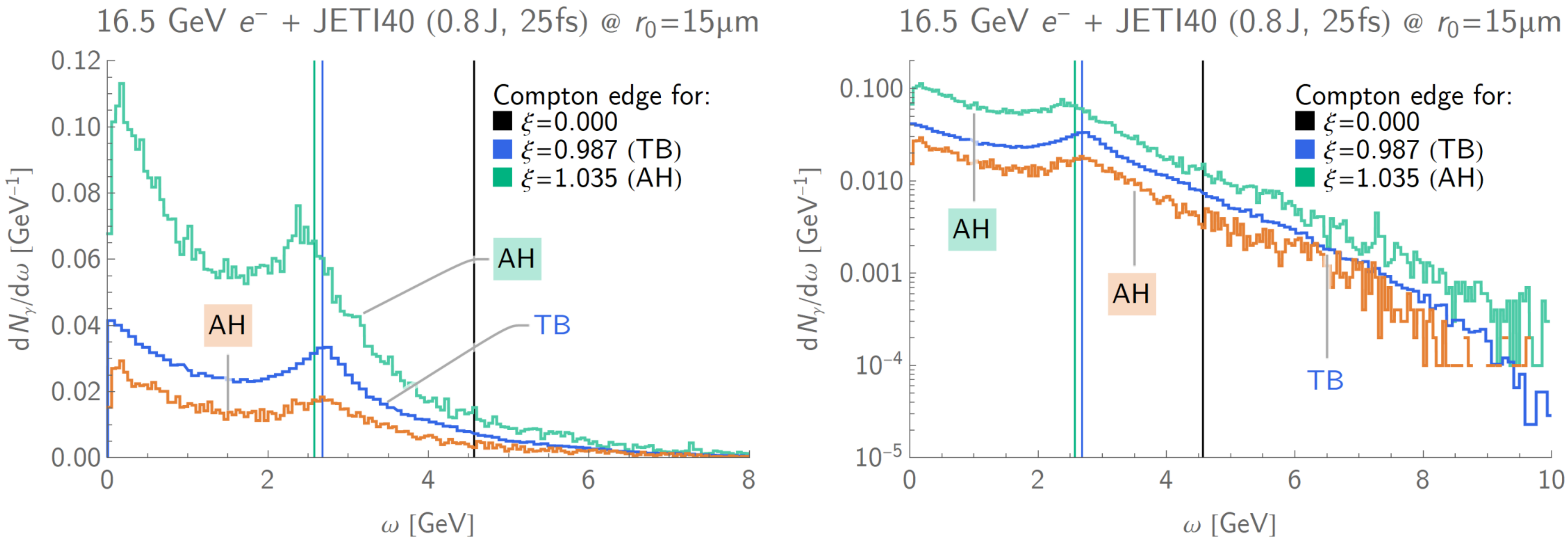




- Photon energy spectrum (normalized per electron), vertical lines give expected position of Compton edges – approximately consistent.

Cross-checks

$r_0 = 15$ microns



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Cross-checks

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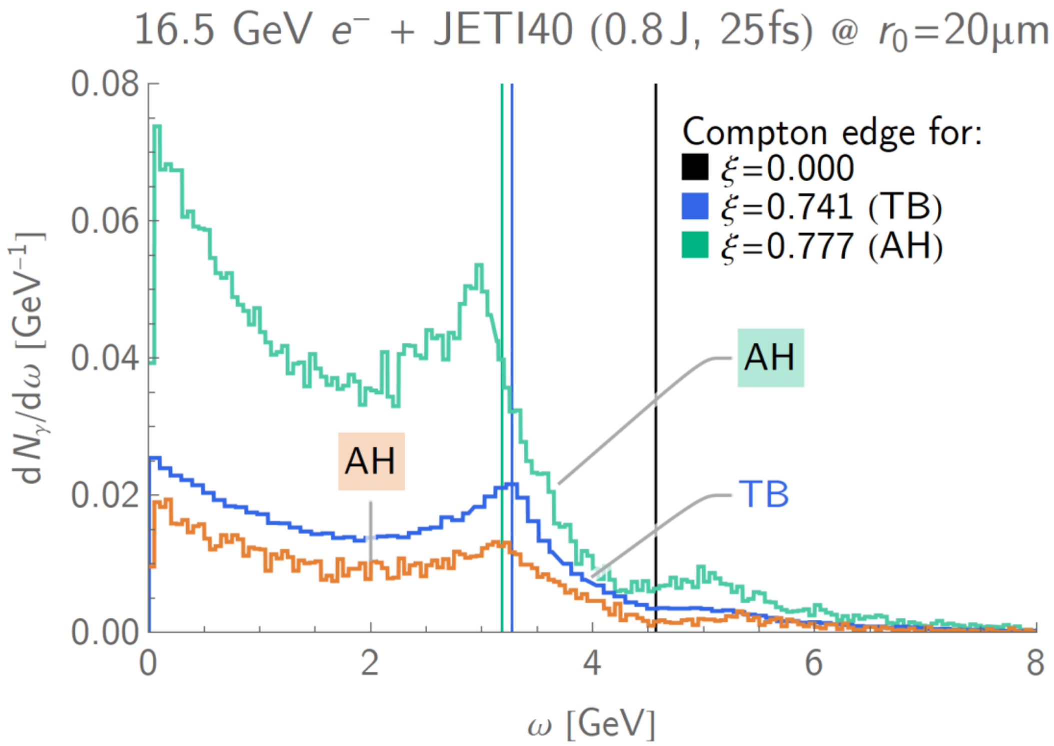

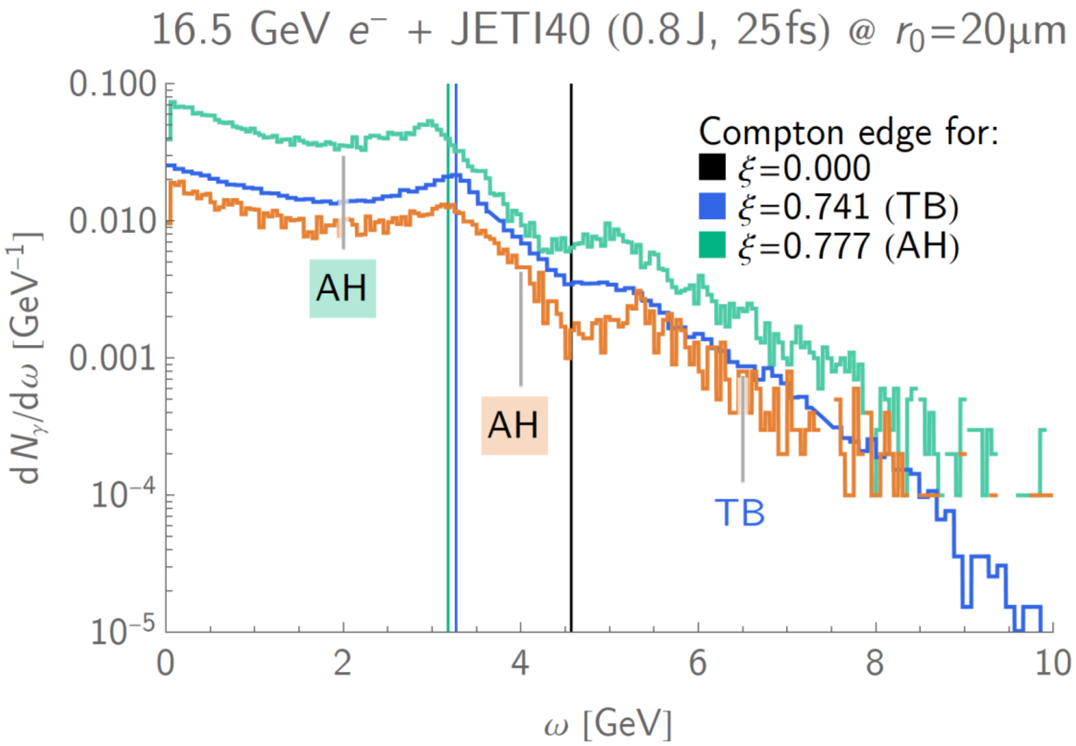

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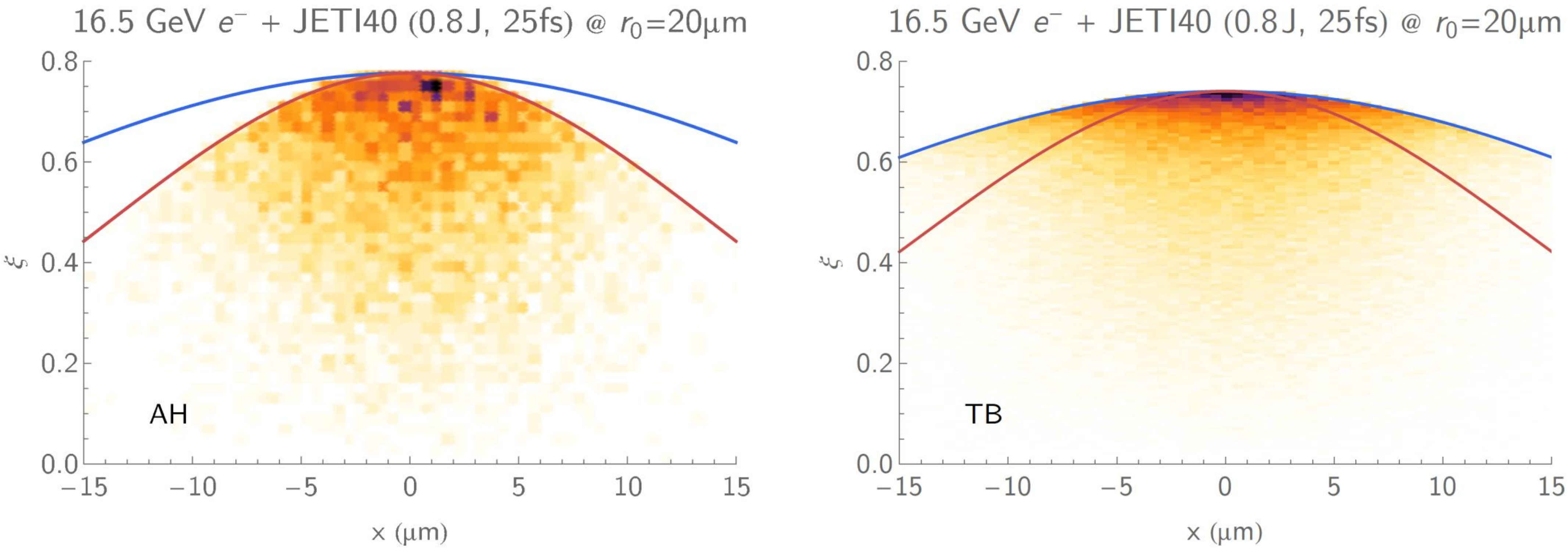

- Probability density that a photon is emitted at given perpendicular distance from the laser axis x and at local amplitude ξ
- Blue = HWHM of 20 microns, red = waist of 20 microns

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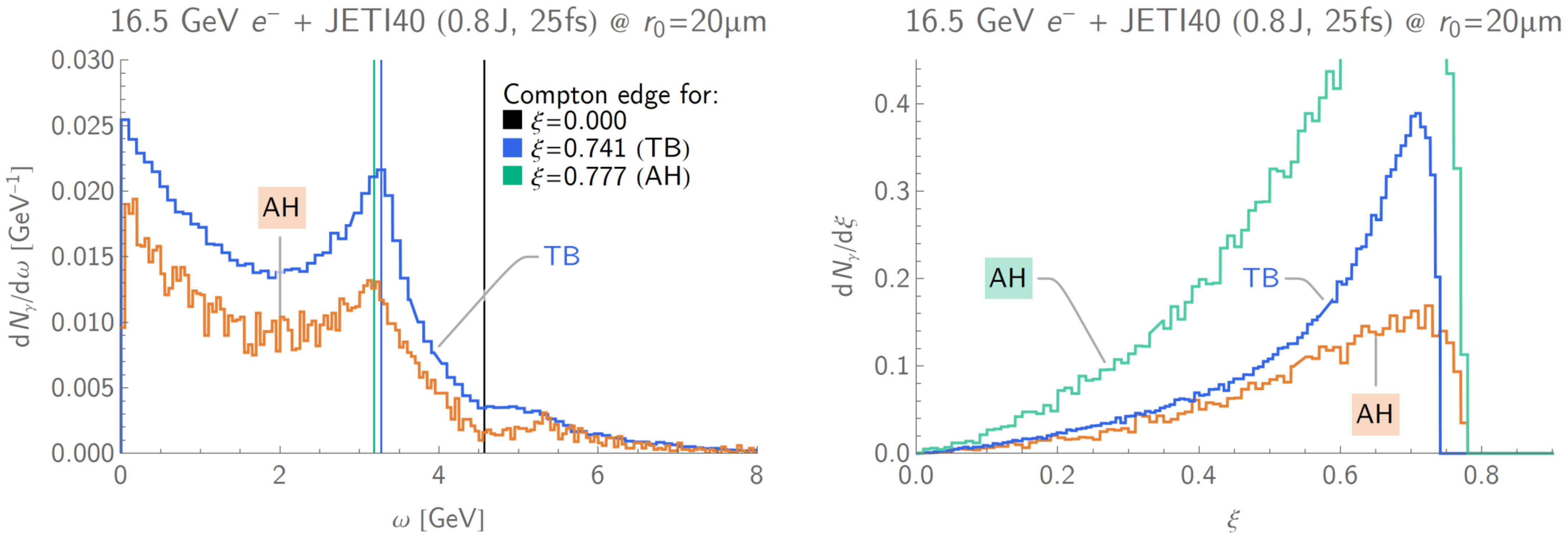

- Rerun simulation with a waist of 20 micron, rather than HWHM of 20 microns, and match peak value of ξ, even though this changes the total energy of the laser.

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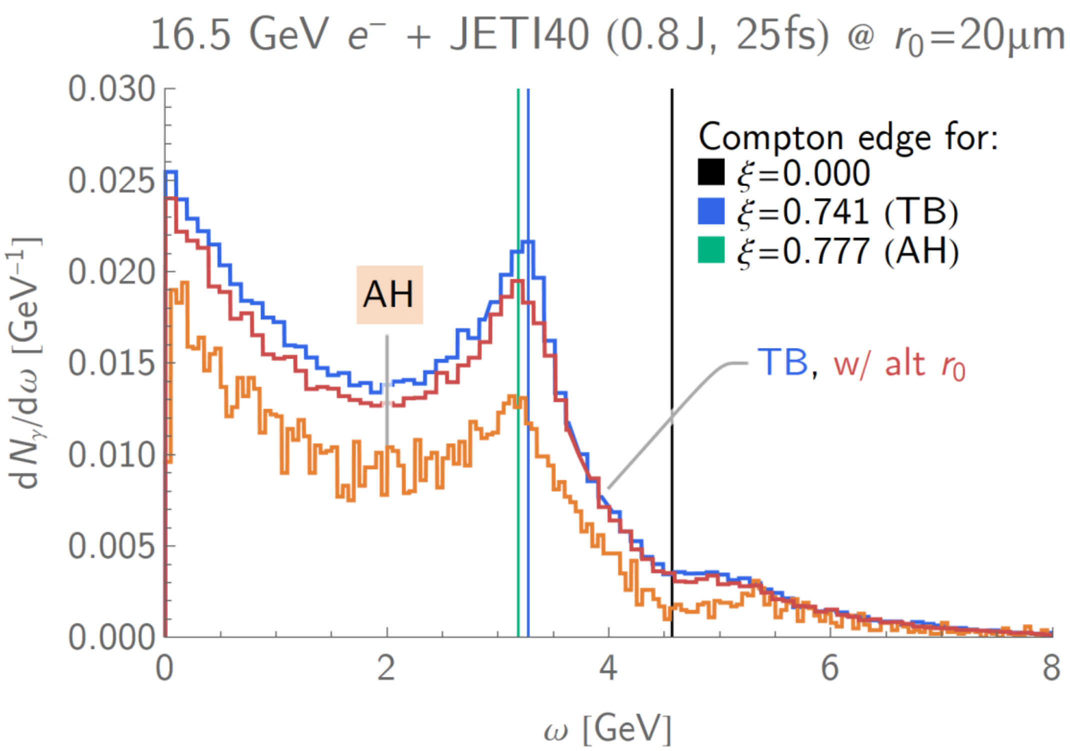

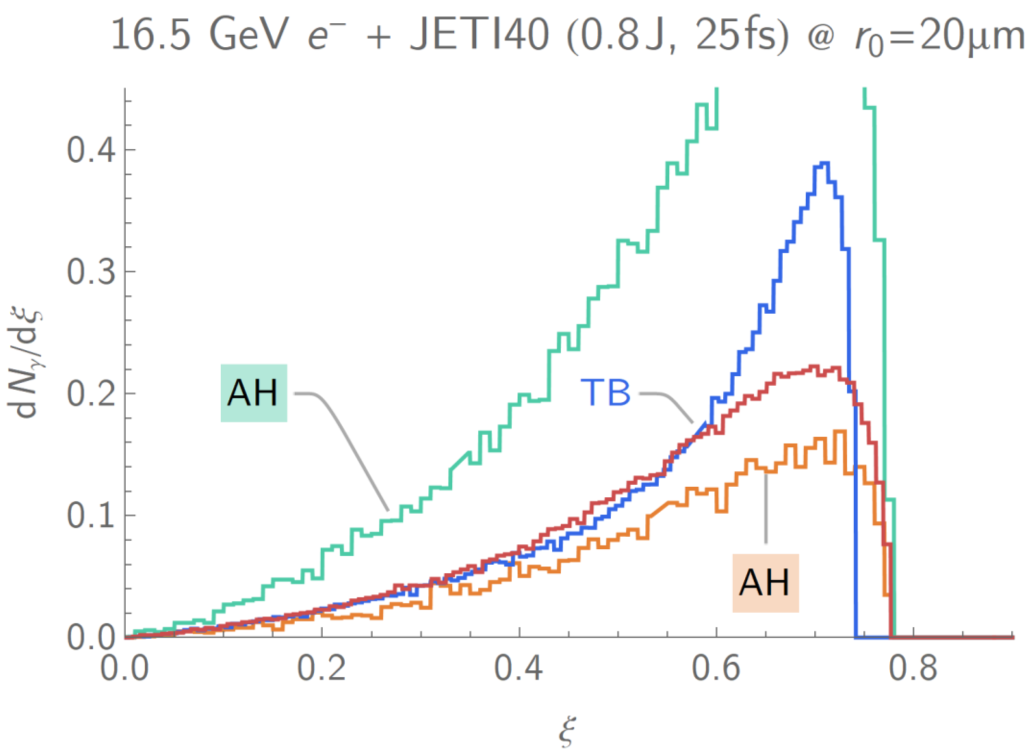

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- Remaining discrepancy is approximately 40%.

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- Codes need to be benchmarked against QED theory (1D and starting to look at 3D).
- So far, unable to reproduce latest IPstrong results for Compton scattering.
- Definition of input conditions unclear: documentation and access to source code essential.

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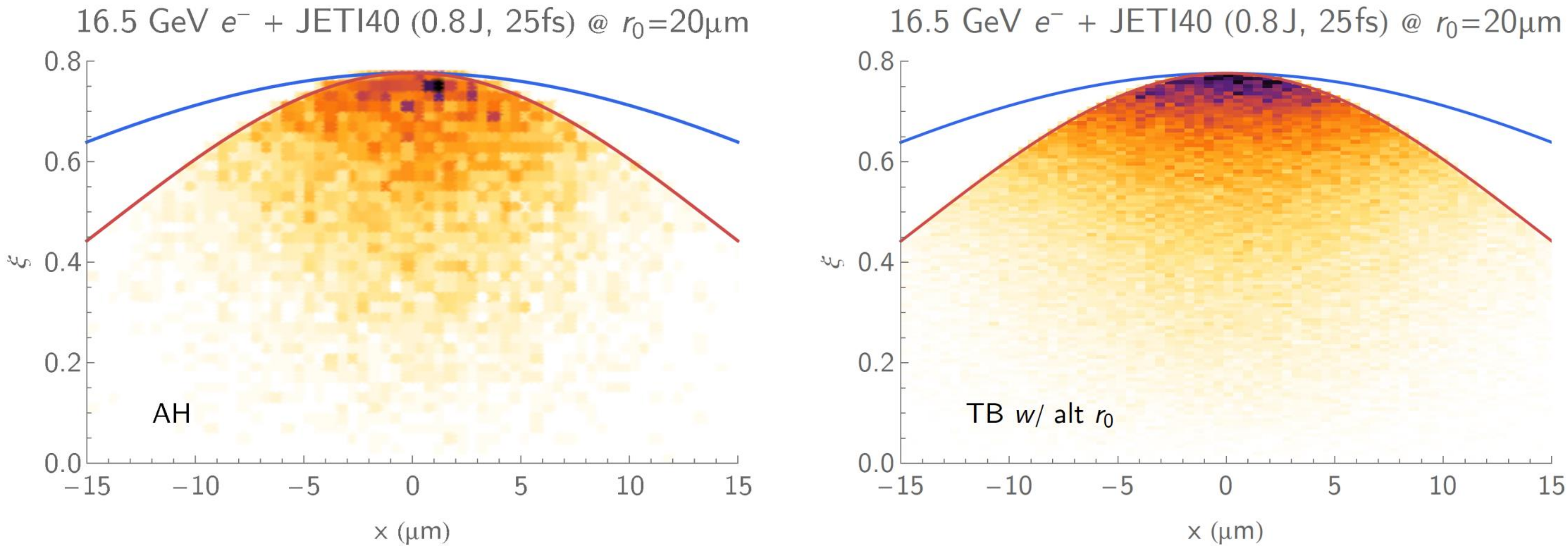

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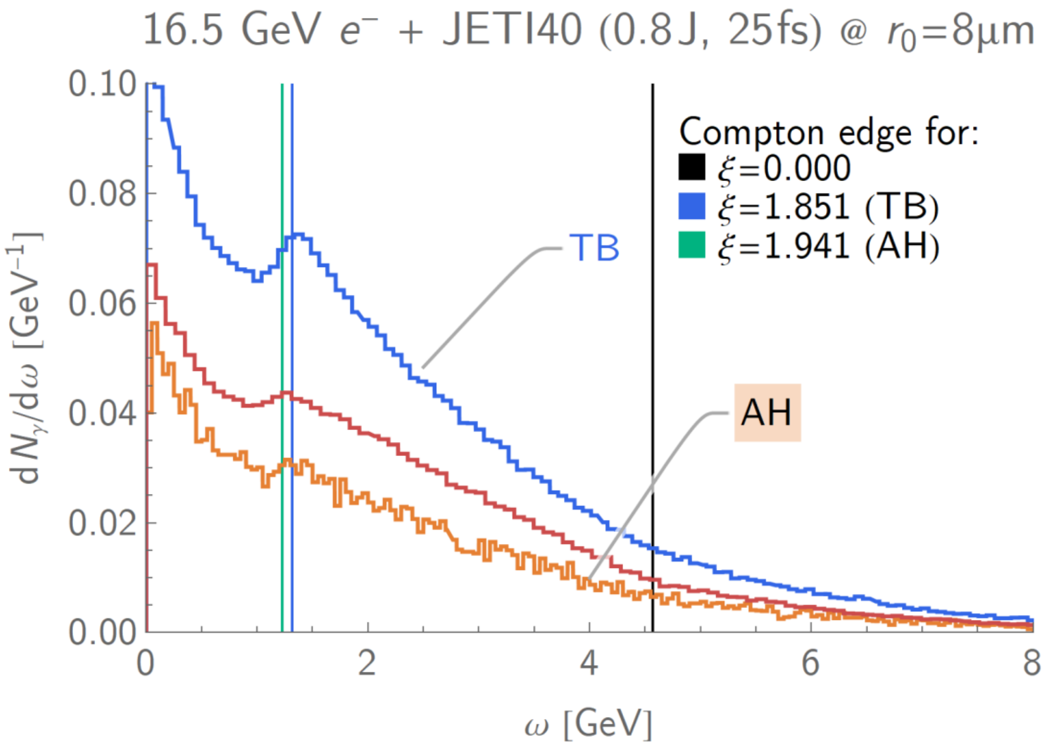

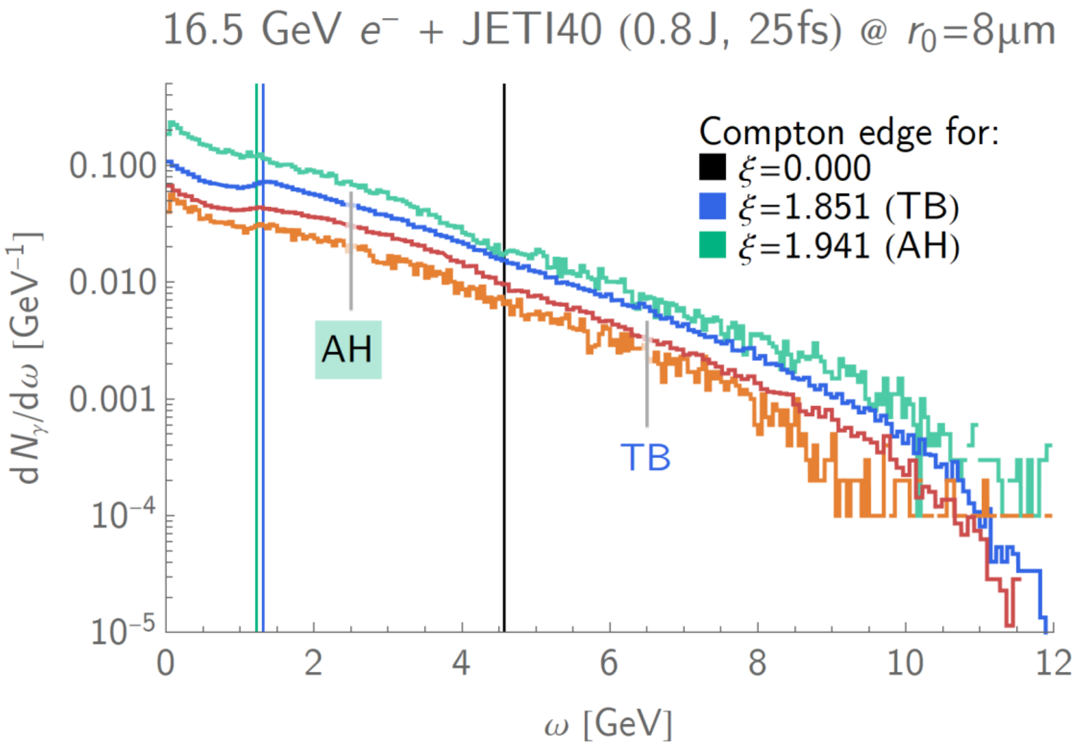

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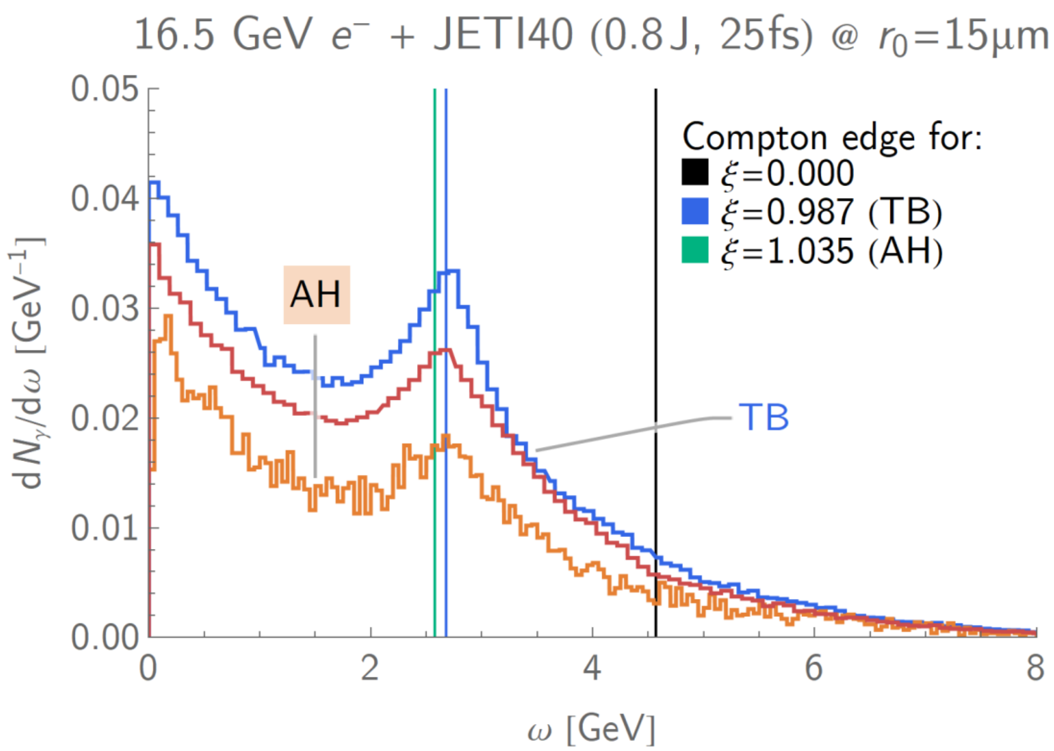

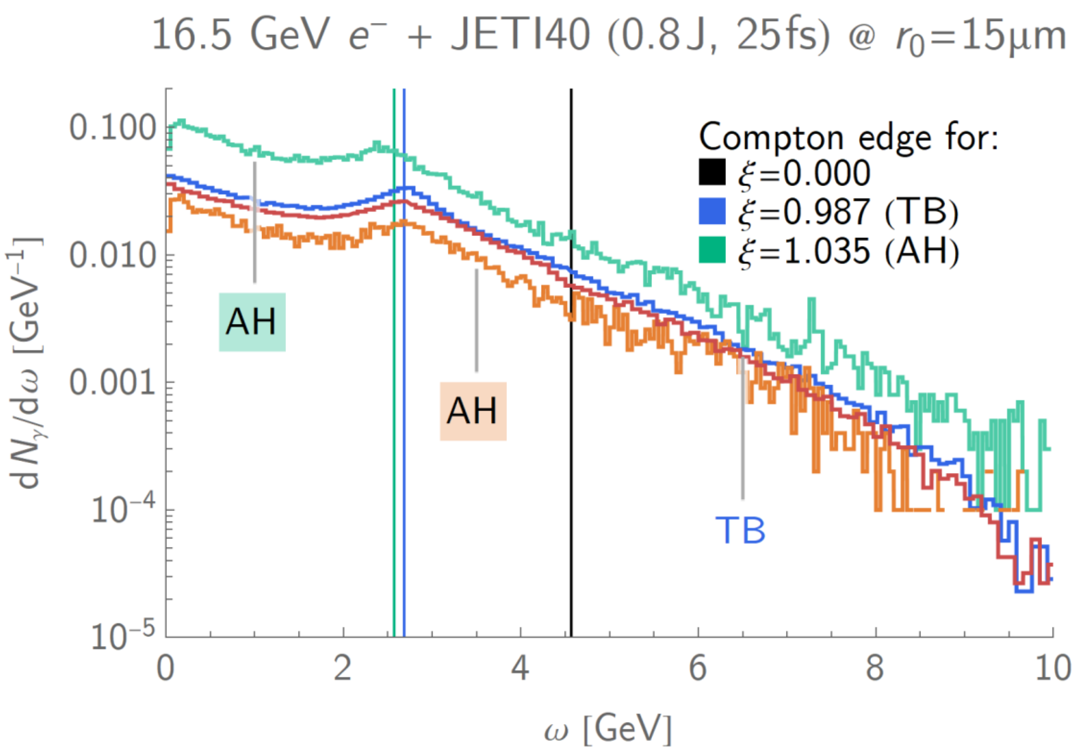

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